KEYWORDS critical Chain • Goldratt • Project Scheduling • Project Management • Buffer sizing • Portfolio Resource Capacity • Multitasking

DOI NUMBER: 10.19255/JMPM01108

THE IMPACT OF GOOD AND BAD MULTITASKING ON BUFFER REQUIREMENTS OF CCPM PORTFOLIOS

ABSTRACT

In project planning, it is presumed that resources will be available to pick up their allocated tasks as planned while what happens in reality is rarely this simple. This discrepancy between planning and reality intensifies in Critical Chain Project Management (CCPM) portfolios where no level of multitasking is allowed. Regarding this, Ghaffari and Emsley (2016) determined the boundary between good and bad multitasking in CCPM portfolios with various resource capacities that showed some limited levels of multitasking could be beneficial to alleviate resource availability issues in such environments. In this paper, the authors aim to investigate how good and bad multitasking affect buffer requirements of CCPM portfolios with the same resource capacities considered in the above study. In a deductive approach, a hypothesis is developed and tested through experiments of ten portfolios with similar size and complexity levels, each one containing four projects with a different resource capacity, and comparing the results to their simulated counterparts obtained by the mentioned study. The results show that buffer requirements of portfolios with resource capacity of 130% and lower can be reduced through allowance of higher levels of multitasking. As a major contribution, a framework for buffer requirements of CCPM portfolios with different levels of multitasking and resource capacity is recommended.

Mahdi Ghaffari
School of MACE
University of Manchester, UK
mahdi.ghaffari@manchester.ac.uk

Margaret W Emsley
Programme Director of the MSc Management of Projects – School of MACE – University of Manchester, UK
margaret.emsley@manchester.ac.uk

1. Introduction

Goldratt *(1997)* extended application of his Theory of Constraints *(TOC)* to project management in a business novel named “Critical Chain” and advocated it as a new method for scheduling and managing single and multiple projects. The method was later called Critical Chain Project Management *(CCPM) (Leach, 2000)* and since then, many authors have studied and critically reviewed its fundamentals, principles and literature: e.g. Leach *(1999, 2003, 2014)*, Lechler et al. *(2005)*, Herroelen and Leus *(2001)*, Ghaffari and Emsley *(2015)*, Trietsch *(2005)*, Raz et al. *(2003)*, Steyn *(2001, 2002)*. Other than the concept of buffer sizing and management that is explained below due to its relevance, main properties of CCPM are: being against multitasking, not considering fixed activity due dates and scheduling non-critical chains to their latest start. It is not within the scope of this study to elaborate on CCPM basics. Thus, readers are kindly referred to the noted studies for further information on CCPM fundamentals, principles and literature.

One prominent feature of CCPM is replacement of task-embedded safety times, as in the critical path method, with various time buffers including the project buffer, feeding buffer, capacity constrained buffer *(CCB)*, resource buffer and drum buffer *(the later two buffers were later realised to be redundant and were replaced with prioritised task lists (Newbold, 2008; Leach, 2014))*. The goal has been to reduce the required safety times by aggregating them in the end of activity chains *(benefiting from the central limit theorem)* and also provide means for a new project monitoring and control system, called buffer management, that is built upon levels of buffer penetration and their demonstration on fever charts.

Appropriate sizing of these buffers is one of the most investigated subjects in CCPM, having led to numerous studies developing a variety of buffer sizing methods. The first author to write on this was Goldratt himself who assumed the embedded safety times consist of about half of duration of each chain and recommended that it is a “good-enough” solution to take out these safety times, cut them by 50% and place them in the end of each chain to protect them against uncertainty *(Goldratt, 1997)*, what was later called the cut and paste method *(C&PM)*. Other authors have attempted to create more scientific and effective rules *(Ghaffari and Emsley, 2015)*; however, despite its weaknesses *(Raz et al, 2003; Tukel et al, 2006; Herroelen and Leus, 2001)*, the 50% C&PM prevailed among CCPM practitioners mostly due to its simplicity and satisfactory performance in most practical cases *(Product Development Institute, 1999; Newbold, 1998; Leach, 2005)*.

More generally, in project planning, it is presumed that resources will be available to pick up their allocated tasks as planned while what happens in reality is rarely this simple. This assumption is the basis for the roadrunner *(relay racer)* mentality prescribed by CCPM within which resources are advised to start and deliver tasks as soon as possible, regardless of scheduled start dates. Moreover, CCPM does not allow multitasking under any circumstances and keeps resources 100% dedicated to a task until it is completed. This can make the resource availability issues even worse because resources cannot switch off a task and pick up a more critical one that is wasting the buffer until the former is finished. A negative consequence of all this might be the need for larger buffers in practice in order to compensate for the time wasted because of absence of the required resources.

Having explained this, in a separate study, Ghaffari and Emsley *(2016)* determined the boundary between good *(multitasking of up to two tasks at a time)* and bad *(multitasking of three and more tasks at a time)* multitasking in CCPM portfolios with various resource capacities and showed that some limited levels of multitasking could be beneficial to alleviate resource availability issues in such environments. However, they failed to elaborate on the impact of the suggested level of multitasking on buffer sizes in CCPM portfolios. Thus, considering that study as a starting point, this paper aims to investigate the effects of good and bad multitasking on buffer requirements of CCPM portfolios with the same resource capacities considered in the above study. The results are expected to address the following research question:

How should time buffer sizes be adjusted according to the level of multitasking and resource capacity to avoid both over-protection and delay in CCPM portfolios?

2. Methodology

The research design for this study has been chosen to be experimental *(Matthews and Ross, 2010)*. As Saunders et al. *(2009)* write, experiments are usually conducted using simulated environments in laboratories. This is also true in the context of this research since it is not possible or practical to undertake projects in reality in order to answer the research question. Therefore, computer experiments are deployed for simulating the implementation of portfolios. The results of experiments are then compared with the probabilistic duration values of the same portfolios as achieved by Ghaffari and Emsley *(2016)* in their study on the boundary between good and bad multitasking. The experiments facilitate testing the following hypothesis:

Shorter buffer sizes can be accounted for by abolishing the ban on multitasking while maintaining a lower level of resource capacity.

The independent and dependent variables of experiments are depicted in **Figure 1**.

Two software packages were used for the experiments:

RanGen: a random project network generator that allows manipulation of more topological measures and resource characteristics than its alternatives such as ProGen, ProGen/Max and DAGEN.

ProChain Pipeline v.11: one of the best-known and long-established CCPM software packages for both single- and multi-project environments. The main reason for choosing the ProChain Pipeline over other packages *(e.g. CCPM+, Concerto and AgileCC)*, apart from its positive reputation and successful history, was the ease of access to the academic version of the software and the fact that it contained the required features for critical chain multi-project scheduling for up to four projects and unlimited number of tasks.

Ten portfolios *(ten different levels of resource capacity)*, each containing four projects with 30 activities *(each task requires a minimum of 2 types of resources (resource use (RU) = 2)* and 4 resource types, are generated using the characteristics mentioned in Tables 1 and 2 *(refer to Demeulemeester et al., (2003)* for definition of jargon used in these tables). The aim has been to generate projects and portfolios that represent a wide variety of project types.

The values of OS and CI considered for each project of a portfolio are depicted in **Table 1** in which the complexity of projects increases from Project 1 to Project 4. From the range of CI values that RanGen generates for every value of OS *(Demeulemeester et al., 2003)*, lowest *(8)* and highest *(24)* were selected for the first and fourth projects respectively and middle values *(15 and 19)* were selected for the other two projects.

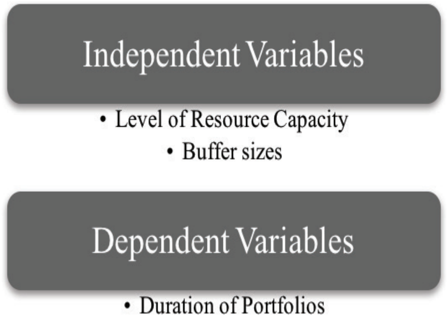

FIGURE 1. *Dependent and independent variables of experiments*

Project 1	Project 2	Project 3	Project 4
OS[1] = 0.2 CI[2] = 8	OS = 0.4 CI = 15	OS = 0.6 CI = 19	OS = 0.8 CI = 24

1. Order Strength, 2. Complexity Index

TABLE 1. *Complexity levels considered for each project in one of the portfolios*

	Resource Types	Resource Use (RU)	Resource Constrainedness (RC)
Portfolio 1	4	2	0.1
Portfolio 2	4	2	0.2
Portfolio 3	4	2	0.3
Portfolio 4	4	2	0.4
Portfolio 5	4	2	0.5
Portfolio 6	4	2	0.6
Portfolio 7	4	2	0.7
Portfolio 8	4	2	0.8
Portfolio 9	4	2	0.9
Portfolio 10	4	2	1.0

TABLE 2. *Resource characteristics of each portfolio*

Based on the above characteristics, ten portfolios, each containing four projects, have been generated using RanGen and modelled in ProChain Pipeline. The models were developed in accordance to CCPM rules for multi-project management through sequencing the projects of each portfolio based on the same constraining resource for all portfolios, as described by Leach *(2014)*.

The dependent and independent variables of the experiments *(**Figure 1**)* are operationally defined to facilitate analysis as follows:

Level of resource capacity: the maximum resource capacity available to each portfolio compared to its requirements. For example, a portfolio with resource constrainedness *(RC)* of 0.5 has 150% rate of resource availability meaning that 50% of total resource capacity remains unallocated.

Buffer sizes: 30%, 40% and 50% feeding and project buffer sizes adjusted by ProChain Pipeline in order to test the hypothesis of the study.

Duration of portfolios: final deterministic duration values, including buffers.

After the experiments were conducted in ProChain Pipeline, the results are compared to the probabilistic duration values obtained by Ghaffari and Emsley *(2016)* for good and bad levels of multitasking.

3. Results

Deterministic duration values of portfolios obtained from the experiments are depicted in **Table 3** below.

Portfolio 1 (RC 0.1)	CCPM with 50% buffers	135
	CCPM with 40% buffers	122
	CCPM with 30% buffers	108
Portfolio 2 (RC 0.2)	CCPM with 50% buffers	128
	CCPM with 40% buffers	112
	CCPM with 30% buffers	98
Portfolio 3 (RC 0.3)	CCPM with 50% buffers	149
	CCPM with 40% buffers	138
	CCPM with 30% buffers	121
Portfolio 4 (RC 0.4)	CCPM with 50% buffers	162
	CCPM with 40% buffers	145
	CCPM with 30% buffers	128
Portfolio 5 (RC 0.5)	CCPM with 50% buffers	160
	CCPM with 40% buffers	146
	CCPM with 30% buffers	131
Portfolio 6 (RC 0.6)	CCPM with 50% buffers	199
	CCPM with 40% buffers	184
	CCPM with 30% buffers	174
Portfolio 7 (RC 0.7)	CCPM with 50% buffers	223
	CCPM with 40% buffers	207
	CCPM with 30% buffers	198
Portfolio 8 (RC 0.8)	CCPM with 50% buffers	224
	CCPM with 40% buffers	215
	CCPM with 30% buffers	206
Portfolio 9 (RC 0.9)	CCPM with 50% buffers	280
	CCPM with 40% buffers	265
	CCPM with 30% buffers	251
Portfolio 10 (RC 1.0)	CCPM with 50% buffers	290
	CCPM with 40% buffers	275
	CCPM with 30% buffers	261

TABLE 3. *Results of experiments conducted by ProChain Pipeline*

For the purpose of making a comparison, the probabilistic results for the same portfolios with different levels of multitasking conducted by Ghaffari and Emsley *(2016)* is identically referenced in **Table 4**.

The comparison of results illustrated in Tables 3 and 4 show that when there is no multitasking, the 50% buffer sizing: underestimates the time required to finish portfolios with RC of 0.1 to 0.6 on time *(inferred from comparing the deterministic and simulated duration values)*, exactly estimates the time required for portfolios with RC of 0.7 and 0.8 and overestimates the time required for portfolios with RC of 0.9 and 1.0. The reductions of probabilistic duration values when the level of multitasking is risen from none to 2 and 3 *(**Table 4**)*, release new capacity for cutting the buffers down to about 40% for the portfolio with RC of 0.7 and 30% or even lower for portfolios with RC of 0.8 to 1.0, regarding the deterministic values of **Table 3**.

It should be noted that while 30% buffer sizes become valid from second level of multitasking for portfolios with RC of 0.9 and 1.0, this happens only from the third level of multitasking for portfolio with RC of 0.8. These reduced buffer sizes could not be applied to other portfolios that also experienced some released capacity after the introduction of multitasking *(RC of 0.4 to 0.6)* because the released capacities were not sufficient to account for at least 10% shorter buffers which is the level of precision considered by this study *(less than 5% shorter buffers might be possible for some portfolios)*. The implications of these data for the research question and hypothesis of this study will be discussed in the next section.

4. Discussion

The aim of this study was to investigate the effects of good and bad multitasking on buffer requirements of CCPM portfolios with the same resource capacities considered in the study conducted by Ghaffari and Emsley *(2016)*. This aim invoked one research question and one hypothesis that are hereby addressed using the achieved results.

How should time buffer sizes be adjusted according to the level of multitasking and resource capacity to avoid both over-protection and delay in CCPM portfolios?

Tables 3 and 4 address this question by providing the required data for drawing a comparison among deterministic with different buffer sizes and simulated duration values. They show that after the introduction of two higher levels of multitasking and releasing some of the unused capacities as the result of this, shorter buffer sizes can be accommodated for in portfolios with RC of 0.7 and higher, as explained in the results section. This supports the hypothesis of this study mentioned in the methodology section above:

Shorter buffer sizes can be accounted for by abolishing the ban on multitasking while maintaining a lower level of resource capacity.

According to this hypothesis, as the resource capacity downsizes, shorter buffer sizes can be accounted for with allowing higher levels of multitasking. Therefore, based on the data of Tables 3 and 4, it can be suggested that with allowing multitasking of up to 3 tasks, a 40% buffer size is appropriate for resource availability of 130% *(RC of 0.7)*

*All numbers are in days (unit of time) *1000 iterations were conducted for each condition		No Multitasking	Multitasking of 2	Multitasking of 3
Portfolio 1 (RC0.1)	Duration with 90% Probability	137	137	137
Portfolio 2 (RC0.2)	Duration with 90% Probability	144	144	144
Portfolio 3 (RC0.3)	Duration with 90% Probability	155	155	155
Portfolio 4 (RC0.4)	Duration with 90% Probability	168	164	162
Portfolio 5 (RC0.5)	Duration with 90% Probability	174	170	168
Portfolio 6 (RC0.6)	Duration with 90% Probability	203	194	190
Portfolio 7 (RC0.7)	Duration with 90% Probability	223	211	209
Portfolio 8 (RC0.8)	Duration with 90% Probability	224	212	209
Portfolio 9 (RC0.9)	Duration with 90% Probability	257	242	237
Portfolio 10 (RC1.0)	Duration with 90% Probability	262	243	240

TABLE 4. *Probabilistic duration values for the same ten portfolios as presented by Ghaffari and Emsley (2016)*

Multitasking Level / Buffer Requirements	No Multitasking	Multitasking of 2	Multitasking of 3
Larger than 50% buffer sizes	RC0.1, RC0.2, RC0.3, RC0.4, RC0.5, RC0.6	RC0.1, RC0.2, RC0.3, RC0.4, RC0.5	RC0.1, RC0.2, RC0.3, RC0.5
50% buffer size	RC0.7, RC0.8,	RC0.6, RC0.7	RC0.4, RC0.6
40% buffer sizes	RC0.9	RC0.8	RC0.7
30% buffer sizes	RC1.0	RC0.9	RC0.8
Lower than 30% buffer sizes	_	RC1.0	RC0.9, RC1.0

TABLE 5. *Buffer requirements of portfolios with RC of 0.1 to 1.0 and various multitasking levels*

going down to 30% buffer sizes for resource availability rates of 120% to 100%. Considering the above hypothesis, linear nature of C&PM for buffer sizing and the duration values of Tables 3 and 4, one implication can also be that buffer sizes can even be shrunk to 20% for portfolios with resource availability rates of 110% and 100% *(RC of 0.9 and 1.0)* when multitasking of 3 is allowed. This demonstrates the higher impact of multitasking in freeing up resources when resource constrainedness is increased. In order to further clarify buffer sizing requirements of portfolios with different levels of resource constrainedness *(RC)* and multitasking, the following table has been developed *(***Table 5***)* using the data from Tables 3 and 4.

5. Conclusions and recommendations

This study investigated the effects of good and bad multitasking on buffer requirements of CCPM portfolios with various resource capacities. A quantitative research method was used to generate, model and experiment on ten portfolios with similar size and complexity levels and different buffer sizes and resource capacities. The results were then compared with the probabilistic duration values of the same portfolios in a previous study to address the aim and questions of this research.

It was shown that shorter buffer sizes can be accounted for by abolishing the ban on multitasking while maintaining a lower level of resource capacity. This was due to release of new capacity when limited levels of multitasking are allowed. A framework was also recommended as a guideline for buffer requirements of portfolios with various levels of multitasking and resource capacity/constrainedness that must be considered with respect to the recommendations of Ghaffari and Emsley *(2016)* regarding the good and bad multitasking in CCPM.

6. Limitations and future research

The validity of results of this study is limited by the extent of effectiveness and capabilities of the software packages that were deployed, namely RanGen and ProChain Pipeline. The available alternatives to these packages and the rationale for choosing them were explained in the methodology section; however, it is certain that their selection over others would have a potential impact on the results. For example, ProChain Pipeline *(the academic version)* dictated that portfolios constitute four projects only and the critical chains and buffers were determined and placed based on its specific algorithms. In addition, the internal resource levelling algorithms and heuristics of ProChain Pipeline is different from any other software.

Another limitation of this study was the usage of generated data instead of real CCPM projects' data. Although deployment of real data could improve validity of the results through consisting many real-life events such as rework or change of resource capacity throughout portfolios, the controllable topological parameters of generated data enabled a more comprehensive research by including varieties of projects with different complexity and resource availability rates.

Considering what was accomplished in this research, a number of suggestions can be made for future research. Firstly, because of the choices made in selection of software packages, aspects of real environment such as rework and iterative work style were not taken into account in modelling and simulations that could be considered for future studies. Secondly, only human resources were considered in this research. This can be extended to a combination of human and non-human resources in future similar studies. Thirdly, with accumulation of historical data about CCPM projects and portfolios through time, real project data can be deployed in future studies instead of generated data.

authors

Mahdi Ghaffari is a PhD candidate at The University of Manchester undertaking his research on resource availability issues in Critical Chain Multi-Project Management and their effects on sizes of buffers in such environments. He has achieved a Bachelors degree (BSc) in Industrial Engineering and Master of Science in Management of Projects. His experience includes working as a project manager of maintenance projects for about three years. He is also certified as PRINCE2 Practitioner by OGC based in the UK and PMP by PMI based in the USA.

Dr. Margaret Emsley is a civil and structural engineer who joined what was then UMIST in 1986, and she is now a Reader in the School of Mechanical, Aerospace and Civil Engineering in The University of Manchester. Previously she had carried out research at Loughborough University and worked as an engineer for Tarmac Construction. She was involved in setting up the MSc in Construction Project Management in 1987 and has contributed to the teaching of many courses at both undergraduate and postgraduate level. She has supervised 13 PhD students and over 150 MSc students and has 7 current PhD students. She is currently the Programme Director of the MSc Management of Projects Group of Programmes (which also includes Commercial Project Management, Construction Project Management and Engineering Project Management).

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